STUDIES FOR STUDENTS

THE EOCENE OF NORTH AMERICA WEST OF THE 100TH MERIDIAN (GREENWICH).[1]

CONTENTS.

[1] The following essay is the outcome of a topical study undertaken by the writer as a student at the University of Chicago. While it is based entirely on the literature of the subject, it brings together so many scattered data concerning a series of formations which often seem intangible to the student, that it is printed in the belief that the summation may be serviceable to students who wish to get information beyond that of text-books, and who have not access to the original reports.—[ED.]

THE Eocene deposits of western North America may be divided into three groups, namely, those laid down in fresh water, those laid down in brackish water, and those laid down in sea water. To these should probably be added those deposited by streams, though this class of formation has not been generally differentiated from the first.

1. *The fresh-water deposits* stretch with many interruptions from New Mexico and Colorado northward and nothwestward through Utah, Wyoming, Montana, North Dakota, the Dominion of Canada, to the Arctic Circle and probably the Arctic Ocean. The formations belonging to this area are the Fort Union, which is the Upper Laramie of the Canadian Geological Survey, the Kenai, Puerco, Torrejon, Wasatch, Bridger, including Green River, Uinta, Huerfano, Mojave, Amyzon, and Manti. In addition there are non-fossiliferous conglomerates which are supposed to be of Eocene age, as follows: Sphinx conglomerate, Pinyon conglomerate, and San Miguel conglomerate.

2. *The brackish-water deposits* extend with interruptions from Oregon through Washington into British Columbia. The formations belonging to this group are Arago and Puget.

3. *The marine deposits* in Oregon and California. The formations belonging to this group are Tyee, Umpqua, Martinez, and Tejon.

In the following pages the known data concerning the distribution and nature of these several formations is summarized, and their correlation as determined by various investigators indicated.

THE FRESH-WATER BEDS.

THE FORT UNION FORMATION.

The Fort Union beds are named from a former military fort on the Missouri River in North Dakota where they are typically exposed. They occur in North Dakota, Montana, extending thence north and northwest into Canada and with interruptions to the Arctic Circle and probably to the Arctic Sea. These beds are thus described by Meek and Hayden[1]: "Beds of clay

[1] Quoted by Clark, U. S. Geol. Surv., Bull. 83, p. 113, 1891.

and sand with round ferruginous concretions and numerous beds, seams, and local deposits of lignite; great numbers of dicotyledonous leaves, stems, etc." Under the name *Paskapoo*, Tyrrell describes this formation as being at least 5700 feet in thickness[1]: "The beds consist of more or less hard, light gray or yellowish-brownish weathering sandstone, usually thick-bedded, but often showing false bedding; also of light bluish-gray and olive sandy shales, often interstratified with bands of hard lamellar ferruginous sandstone, and sometimes with bands of concretionary blue limestone, which burns into an excellent lime. The sandstones consist of very irregular, though slightly rounded, grains of quartz, felspar, and mica, cemented together in a calcareo-argillaceous matrix."[2] Its fauna shows that this entire series is of fresh-water origin.

Because of the nature of the stratigraphy of the rocks of this region, and because of the fact that dinosaurs became extinct immediately before the Paskapoo epoch, because a time of great disturbance "in which the Rocky Mountains were uplifted" preceded the Paskapoo, Tyrrell thinks this break between the Cretaceous and Paskapoo marks the close of the Cretaceous, "and that the Tertiary epoch began with the commencement of the Paskapoo period, during which a great thickness of sandstones and sandy shales was laid down without any apparent break or unconformity. In this Paskapoo series, then, we have the representative of the Eocene of Europe."[3]

Weed, writing of the Crazy Mountains of Montana, says[4]: "These mountains are formed of Livingston beds, conformably overlain by a series of sandstones and clay shales, characterized by fresh-water fauna, and lithologically distinct and readily differentiated from the somber-colored sandstones of volcanic material composing the Livingston beds. The plant remains of these [upper] beds are not of Laramie nor of Denver bed types, but are species characteristic of the strata in the vicinity of Fort

[1] Geol. and Nat. Hist. Surv. of Canada, Ann. Rep. n. s., Vol. II, p. 135 E. 1886.

[2] TYRRELL: loc. cit., p. 136. [3] Loc. cit., p. 138.

[4] Amer. Geol., Vol. XVIII, pp. 204, 205, 1896.

Union, and that name is therefore adopted for the formation." A section is given showing Fort Union beds to be 4648 feet thick at this place. "The importance of this section, which is the only one known to the writer in which the Fox Hills, Laramie, Livingston, and Fort Union formations occur superimposed, is apparent when it is considered that in eastern Montana and Canada the Fort Union rests directly upon Laramie beds in apparently perfect conformity."[1] Vertebrate fossils were not found, but the invertebrate fossils from the Fort Union beds at this place were submitted to Stanton, who reported that "almost all the species of the list were originally obtained near Fort Union on the Missouri River."[2]

Of Fort Union fossils in the United States National Museum, Weed says[3]: "They have been studied by Professor Knowlton, who reports that the Fort Union flora embraces 169 species. Of this number 130 species are confined to this formation. Of the 39 species found in other terranes, 21 occur in the Miocene, 14 in the Denver (post-Laramie), and 9 in the Laramie. These figures tell their own story." Knowlton states that the flora as a whole is clearly Eocene. This confirms the statement of Newberry that the floras of the Laramie and the Fort Union are totally distinct, "and that these formations should be referred to different geological horizons, the Fort Union to the Tertiary, and the Laramie to the Cretaceous." Weed gives the following table showing "the comparative sections found along the Rocky Mountain front."[4]

Age	Montana	Canada	Colorado
Eocene	Fort Union	Paskapoo { Porcupine Hills 570c′ { Willow Creek	
Post Laramie	Livingston	(Erosion interval)	*b.* Denver beds *a.* Arapahoe beds
	Unconformity		Unconformity
Cretaceous	Laramie	Edmonton (Tyrrell) or Wapiti River (Dawson)	Laramie

[1] WEED: loc. cit., p. 206.

[2] Quoted by Weed, loc. cit., pp. 206, 207.

[3] WEED: loc. cit., p. 210.

[4] Loc. cit., p. 211.

This conclusion concerning the age of the Fort Union formation has been supported by the Dawsons, as shown by the following: "Dr. G. [M.] Dawson and the writer [Sir William Dawson] have, ever since 1875, maintained the lower Eocene age of our [Canadian] Laramie, and of the Fort Union group of the northwestern United States. . . . ."[1]

THE PUERCO FORMATION.

The Puerco formation is located in northwestern New Mexico at the headwaters of Puerco River, from which the formation takes its name, and where it "reaches a thickness of outcrop of about 850 feet."[2] The rocks of this formation consist of "sandstones and gray and green marls."[3] The formation is thus characterized by Wortman:[4] "The thickness of the beds is roughly estimated at 800 to 1000 feet, and as far as can be observed they lie conformably upon the Laramie."

The fossils occur at two horizons which are separated by barren strata 700 to 800 feet thick (not 30 feet as erroneously quoted by Dall in the Eighteenth Annual Report U. S. Geol. Surv., Part II, p. 347). "The lower fossil-bearing strata occur in two layers, the lowermost of which lies within 10 or 15 feet of the base of the formation. This is succeeded after an interval of about 30 feet by a second stratum in which fossils are found. . . . . Both of these strata are red clay, and at no place did we find them more than a few feet in thickness."[5]

This horizon "is especially and sharply distinguished by the occurrence of the remains of Polymastodon, which appear to be entirely absent from the upper horizon."[6] The upper horizon is richer in fossils than the lower. "The genera Chirox and Pantolambda appear to belong exclusively to the upper beds."[7]

[1] Quoted by Knowlton, Bull. V, Geol. Soc. Amer., p. 589, 1894.

[2] CLARK: U. S. Geol. Surv., Bull. No. 83, p. 138, 1891.

[3] CLARK: loc. cit., p. 138.

[4] Quoted by Osborn, Bull. Amer. Mus. Nat. Hist., Vol. VII, p. 1, 1895.

[5] WORTMAN: quoted by Osborn, loc. cit., p. 2.

[6] *Ibid.* [7] *Ibid.*

Wortman believes that the upper fossiliferous horizon contains several layers, and that their vertical range is somewhat greater than that of the lower horizon." Matthew states that the "Upper and Lower Puerco beds do not contain a single species in common, and only three or four genera pass through. The two faunas are entirely distinct. Dr. Wortman proposes to call the upper beds the Torrejon formation, retaining the name Puerco for the lower beds."[1] Scott correlates the Puerco with the Cernaysien of Europe.[2]

THE WASATCH FORMATION.

The Wasatch formation occurs in a large area in Utah, Wyoming, and Colorado. It is equivalent to the Vermillion Creek of King; Bitter Creek of Powell; and Coryphodon beds of Marsh. The fossils indicate that the rocks were deposited in fresh water. "From the outcrops thus broadly sketched it is clear that a single lake extended from longitude 106° 30′ to 112°, stretching northward probably over the greater part of the Green River Basin, and southward to an unknown distance."[3]

The Wasatch beds lie upon the Cretaceous with a discrepancy in dip, as shown by King, of 0° to 25° in many places. Clark says:[4] "The Wasatch strata throughout much of their extent are conformable to the Laramie, but in western Wyoming and eastern Utah a marked unconformity is exhibited." King thus describes the Wasatch formation, which he names Vermillion Creek:[5] "It is made up of a heavy gritty series at the base, which in the region of Vermillion Creek and north of Evanston is gray, but as displayed at Echo Canyon and East Canyon Creek is characterized by the presence of enough red sandstones and clays to give it more of a brick or in places a deep pinkish color. The middle members are of finer material and are more intercalated with clays, while the upper part of the series has shown wherever the group comes in contact with the Green

[1] Science, n. s., Vol. VII, p. 852, 1897. [2] Science, n. s., Vol. II, p. 499, 1895.
[3] KING: U. S. Explorations of the 40th Parallel, Systematic Geol., Vol. I, p. 374.
[4] Loc. cit., p. 139. [5] Loc. cit., p. 375.

River series, is made up of striped and banded sandstones, varying from gray to yellow, white, and red, with prevailing white and red tints. As regards the relations of this with the underlying group, it should be repeated that the evidence has finally accumulated so that there can be no longer a doubt where to draw the line between the Cretaceous and the Tertiary series. I unhesitatingly say that the bottom of the Vermillion Creek is the base of the Tertiary, and that it rests in essential unconformity (though locally in accidental conformity) upon the Cretaceous."

Scott, in a paper read before the British Association, correlates the Wasatch with the Suessonien of Europe.[1]

THE BRIDGER FORMATIONS (including Green River and Wind River).

The Bridger is divided by Scott[2] into two substages, namely, Wind River substage (=Green River substage), and Bridger substage. The Bridger deposits are less extensive than the Wasatch.[3] The Wind River beds lie chiefly in the valley of Wind River, Wyoming, east of the Wind River Mountains. The width of their outcrop is from one to five miles, and its length about 100 miles. The beds reach a thickness of 1000 feet, and are composed of sandstones and shales.

The Green River beds are in the valley of the Green River in Wyoming, Colorado, and Utah, on the west side of Wind River Mountains. Paleontological evidence shows them to be of essentially the same age as the Wind River beds, hence the appropriateness of this name for both series. Outliers of Green River beds occur west to about longitude 116° W. in Nevada, and King interprets this fact as showing that the waters in which they were deposited were probably bounded by the Piñon Mountains.[4] "The Green River series rests for the most part unconformably upon the horizontal as well as the highly inclined Vermillon Creek [Wasatch] beds."[5] These beds are described

[1] Science, n. s., Vol. II, p. 499, 1895. [2] Introduction to Geology, p. 496, 1897.
[3] SCOTT: loc. cit., p. 499. [4] Loc. cit., p. 393. [5] KING: loc. cit., p. 378.

as "calcareous sands and slightly siliceous limestones, which are overlaid by remarkably fissile shales." The limestones are about 800 feet thick; the shales 1200 feet thick. The beds contain fresh-water fossils but "no brackish-water forms whatever."[1]

The formation of the Bridger substage is described by King[2] as follows: "Throughout the middle of the Bridger Basin it rests in positions of complete horizontality, and throughout its whole extent shows no evidence of orographical disturbance, such as could be registered in local changes of angle. The aggregate thickness of the beds of this group is estimated as between 2200 and 2500 feet. The material is almost wholly made up of fine sand and clay, arranged in varying proportions and occasionally slightly changed by calcareous mixtures." Scott correlates the Bridger with the Parisien of Europe.[3]

THE HUERFANO FORMATION

The Huerfano beds in Huerfano county, Colorado, were first described by R. C. Hills in 1888. He estimated the thickness to be 8000 feet and made three divisions of the beds. In 1891 Hills identified the upper beds, which consist of clays, soft shales and sand, as Bridger, and estimated its thickness at 3300 feet. Below this lie the Cuchara beds 300 feet thick, and below the Cuchara are the Poison Canyon beds 3500 feet thick. The lower two divisions he considered Lower Eocene. In 1897 Osborn and Wortman visited the region and arrived at the following conclusions[4]: (1) "That west of Huerfano Canyon the variegated marls, clays, soft shales and sands aggregate only 800 to 1000 feet in thickness and are nearly horizontal in position. They may be positively divided into upper beds equivalent to the Bridger,[5] and lower beds, equivalent to the Wind River or Upper Wasatch.

[1] KING: loc. cit., p. 389. [2] Loc. cit., p. 400.

[3] Science, n. s., Vol. II, p. 499, 1895.

[4] OSBORN: Bull. Amer. Mus. Nat. Hist., Vol. IX, p. 250, 1897.

[5] "Bridger" and "Wind River" appear to be used in the sense of "Bridger substage" and "Wind River substage" respectively as used by Scott. Cf. SCOTT'S Introduction to Geology, p. 496, table.

These constitute the only true Huerfano deposits. (2) That the Cuchara and Poison Canyon beds are unconformable with the Huerfano beds and older than the Eocene, probably marine cretaceous as partly determined by the presence of a species of *Baculites* in the yellow sandstone of the typical Poison Canyon section. (3) That the present canyon of the Huerfano River cuts through the base of the main anticlinal axis of post-Laramie origin, which formed the eastern boundary of the lake. This axis extended to the south so as to include the base of Silver Mountain toward the Cuchara divide; but it lies from three to seven miles west of the anticlinal axis described by Professor Hills. (4) That the Huerfano lake deposition did not extend as far to the east or south as Spanish Peaks, and that the variegated beds observed there are of older origin. This would materially affect the geological age of the prominent neighboring laccoliths."

From the above conclusions it will be observed that the Huerfano beds are much more restricted geographically than was supposed by Hills. They occupy a part of the basin of the upper part of Huerfano River, between the Wet Mountains on the northeast and the Sangre de Cristo and Culebra ranges on the west and south. Osborn thinks the beds were formed by the damming of the Huerfano River by a post-Laramie axis of uplift which was afterward trenched by the river. The lake was thus drained.

It appears from Osborn's conclusions that the two divisions of the Huerfano beds represent the two substages of the Bridger stage of Scott. The name Huerfano should be restricted to one of these divisions. The other division should receive a new name.

THE UINTA FORMATION (=Brown's Park group of Powell).

The Uinta formation was named by King from the Uinta Mountains, on the flanks of which its outcrops occur. The Uinta is described as follows[1]: ". . . . it is possible that this group was deposited continuously, at least in part, with the Bridger

[1] Quoted by Clark, loc. cit., p. 143.

group, but at the places where the junction between the two groups have been seen in this region there is an evident unconformity, both of displacement and of erosion. The group consists of fine and course sandstones, with frequent layers of gravel, and occasionally both cherty and calcareous layers occur. The sandstones are sometimes firm and regularly bedded, and sometimes soft and partaking of the character of bad land material. The color varies from gray to dull reddish-brown, the former prevailing north of the Uinta Mountains, the latter south of them." King says the lower members of the Uinta group are, "chiefly rough, gritty conglomerates, passing up into finer grained sandstones, and at certain points developing creamy, calcareous beds."[1]

The vertebrate fossils show the Uinta to be a fresh water deposit. Scott notes that a considerable break [physical?] occurs between the Bridger and the Uinta, and that earth movements took place at this time. He makes the Uinta equivalent to the Paris gypsum deposits[2]. Peterson finds the following succession of strata in the Uinta basin.[3] (1) Wasatch; (2) conformably upon Wasatch, Green River; (3) conformably upon Green River, a series of hard, brown sandstones, alternating with greenish-gray clays; (4) conformably upon this are layers of coarse, brown sandstone alternating with shales; (5) "*true Uinta* or Brown's Park beds of a fine grained soft material . . . . of brick-red color." These last named beds are about 600 feet thick. Describing the highest three (3, 4, and 5 above) Peterson says:[4] "This uppermost strata [stratum] of the Uinta basin has hitherto been reported as resting unconformably upon the Bridger sediment, but no observable breaks were found to distinguish the true Uinta from underlying Bridger sediment. So the writer found it necessary in collecting fossils to divide the beds overlying the Green River shales into three different levels, which are here arranged alphabetically in ascending position

[1] Loc. cit., p. 405. [2] Science, n. s., Vol. II, p. 499, 1895.

[3] Quoted by Osborn, Bull. Amer. Mus. Nat. Hist., Vol. VII, p. 73, 1895.

[4] Quoted by Osborn, loc. cit., p. 74.

[A being lowest]: Horizon C, true Uinta beds 600 feet thick, sandstones and clays brownish and reddish, ferruginous . . . . "Horizon B, 300 feet thick. Soft coarse sandstones and clays. Horizon A, 800 feet thick. Hard brown sandstones immediately overlying the Green River shales." Commenting upon the above field notes Osborn says[1]: "These excellent observations supply one of the most important links in the American lake faunal chain, namely that between the Washakie[2] and the Uinta. The explorations of the present year, 1895, may modify these results, but it is certain we have now not only established a complete faunal transition from the Bridger and Washakie beds upon the one side, to the true Uinta level or Horizon C upon the other, but have demonstrated a closer connection between the fauna of this basin and that of the lowest White River Miocene."

THE AMYZON FORMATION

Under this name Cope has described beds in Elko county, Nevada; in South Park, Colorado; and in central Oregon. He regards them as belonging to the "later Eocene or early Miocene eras."[3] King described and mapped the same beds of Nevada as of Green River age.[4]

Cope thus describes the beds of Oregon: "The regions of the John Day River and Blue Mountains, furnish sections of the formations of central Oregon. . . . . Below the Loup Fork follows the Truckee [Neocene] group, so rich in extinct mammalia, and below this a formation of shales. These [shales] are composed of fine material and vary in color, from a white to a pale brown and reddish-brown They contain vegetable remains in excellent preservation, and undeterminable fishes. The *Taxodium* nearly resembles that from the shales at Osino, Nevada, and on various grounds I suspect that these beds form a part of

[1] Loc. cit., pp. 74, 75.

[2] Beds belonging to the upper part of the Bridger substage lying east of Green River in southern Wyoming. Cf. Clark, U. S. Geol. Surv., Bull. No. 83, pp. 117, 142.

[3] Amer. Nat., Vol. XIII, p. 332, 1879.

[4] U. S. Geol. Explorations of the 40th Parallel, Vol. I, Systematic Geol., p. 393, 1878.

the "Amyzon Group" (*American Naturalist*, June 1880), with the shales of Osino and of the South Park of Colorado."[1] The Amyzon beds of Nevada appear in the accompanying map. Those of Colorado and of Oregon are not here mapped.

THE MANTI FORMATION

Cope has described this formation as follows:[2] "There is, however, a series of calcareous and silico-calcareous beds in central Utah, in Sevier and San Pete counties, which contain the remains of different species of vertebrates than those which have been derived from either the Green River or Amyzon beds. These are *Crocodilus*, sp., *Clastes cuneatus* Cope, and a fish provisionally referred to *Priscacara* under the name *P. testudinaria* Cope. There is nothing to determine to which of the Eocenes this formation should be referred, but it is tolerably certain that it is to be distinguished from the Amyzon beds. In its petrographic characters it is most like the Green River, as it consists in large part of shales. The laminae are generally thicker than those of Green and Bear rivers. The genera *Crocodilus* and *Clastes* have not been found heretofore in Green River beds, although they are abundant in the formations deposited before and after that period. Until its proper position can be ascertained, I propose to call the formation the Manti beds."

Some years later Cope regarded these beds as of probably Wind River age. He says, "A probable second locality of this [Wind River] formation is known in eastern Utah, in the Wasatch Mountains. This formation is known as the Manti beds."[3]

THE MOJAVE FORMATION

Fairbanks has described[4] a formation in southeastern California which is probably Eocene. "On the northern slope of the El Paso range, between Mojave and Owen's Lake, there is a series of beds of clays, sandstone, volcanic tuffs, and interbedded

[1] Proc. Amer. Philos, Soc., Vol. XIX, p. 61, 1880.

[2] Amer. Nat., Vol. XIV, pp. 303, 304, 1880.

[3] *Ibid.*, Vol. XXI, p. 454, 1887.

[4] Geology of eastern California, Am. Geol., Vol. XVII, p. 63, 1896.

lava flows. These are probably 1000 feet or more in thickness and extend over a considerable area between the El Paso range and the Sierra Nevadas. . . . . They are finely exposed in Red Rock canyon and about Black Mountain. . . . . The beds are tilted northward at an angle of 15–20 degrees. . . . . Impressions of leaves occur in the clay immediately above the seam of coal. These were submitted to Dr. F. H. Knowlton who says: 'I have looked over the three small fragments of fossil plants from the Mojave desert with the following result: Two species are represented, *Spindus affinis* Newb., and *Anemia subcretacea* (Sap.) Ett. and Gard. . . . . The plants indicate a Tertiary age without doubt, and they seem to belong to the Eocene. Both species have quite a wide distribution geographically and are confined, with several unimportant exceptions, to the Eocene.'"[1]

EOCENE OF BATES HOLE, WYOMING

In the valley of Bates Creek, Natron county, Wyo., fossiliferous Eocene beds occur. They have been but recently recognized and no published account of them is known to the writer.

THE KENAI FORMATION

The coal bearing beds typically seen on Kenai peninsula, Cook Inlet, Alaska, "but widely spread in British Columbia and over the coast of Alaska and its adjacent islands" are called by Dall and Harris the Kenai group.[2] Cretaceous Aucella beds lie beneath the Kenai, but whether marine beds of the same age as Kenai intervene is uncertain.[3] "In Alaska, at Cook's Inlet, at Unga Island, at Atka and at Nulato in the Yukon valley we find the leaf beds of the Kenai group immediately and conformably overlain by marine beds containing fossil shells which are common to the Miocene of Astoria, Oregon, and to middle and southern California."[4] Kenai rocks consist of "great thicknesses of somewhat loosely consolidated conglomerates, sandstones, and shales, all generally greenish in character. They contain everywhere

[1] FAIRBANKS: loc. cit., pp. 67, 68.

[2] DALL and HARRIS, Bull. No. 84 U. S. Geol. Surv., pp. 234 et. seq., 1892.

[3] *Ibid.*, loc. cit., p. 251.

[4] *Ibid*, loc. cit., p. 251.

plant remains and frequent seams of lignite, and rest unconformably upon the older formations."[1]

The conclusion concerning the age of the Kenai is based upon its fossil plants and upon its stratigraphic relations. In 1892 Dall, after a summary of the evidence, concludes that the Kenai "is probably of Eocene age. . . . . "[2] In 1896 Dall says, "When we consider that the Oligocene Aturia bed is immediately and conformably overlain at Astoria, Oregon, by shales and sandstones undoubtedly equivalent to the Alaskan marine Miocene, and that the latter, in like manner, immediately and conformably overlies the Kenai group it must be considered that the view that the latter is Oligocene seems highly probable."[3]

In the following year Dall places the Kenai beds in the Eocene, remarking that, "They are with little doubt coeval with the Atane beds of Greenland and other arctic leaf-bearing strata. Their exact horizon is doubtful, but some of the plants appear to be common to the lignitic beds of the Mexican gulf coast, and they are provisionally placed here awaiting more definite information."[4]

BRACKISH WATER DEPOSITS

THE PUGET FORMATION

The Puget formation occurs in Washington in the Puget Sound basin upon the western flank of the Cascade range, extending to Burrard's Inlet, British Columbia. At Comox and elsewhere in Vancouver Island. On the eastern side of the Cascade Mountains beds occur which are lithologically like the Puget formation and probably belong to it.[5] No fossils have been found in these beds east of the mountains. The Puget formation is thus described by Willis and Smith:[6]

[1] SPURR: Eighteenth Ann. Rep. U. S. Geol. Surv. for 1896–7, Part III, Economic Geology, p. 194.

[2] DALL and HARRIS: loc. cit., p. 252.

[3] DALL: Seventeenth Ann. Rep. U. S. Geol. Surv., 1895–6, Part I, pp. 841, 842.

[4] Eighteenth Ann. Rep. U. S. Geol. Surv., 1896–7, Part II, p. 345.

[5] SIR WILLIAM DAWSON: Trans. Roy. Soc. Can., n. s., Vol. I, pp. 137, 138, 1895.

[6] Geol. Atlas of the U. S., Tacoma Folio, Washington, 1899.

The Puget formation consists of interbedded sandstones, shales and coal beds aggregating 10,000 feet or more in thickness. Sandstones prevail. They are of variable composition, texture, and color, and are frequently cross stratified. Their composition ranges from a typical arkose, consisting of slightly washed granitic minerals to siliceous clays. The separate beds vary from a few inches to more than 100 feet in thickness. Conglomerates and concentrated quartz sands have not been observed. The variations in color are not such as to distinguish upper and lower sections of the formation. In general the strata are similar and are similarly interbedded from top to bottom.

The shales of the Puget formation are formed of siliceous clayey muds containing sometimes considerable carbonate of iron, and generally more or less carbonaceous matter, which varies in character from finely divided organic material to large leaves and stems. . . . .

Carefully measured sections show that the Puget formation contains more than 125 beds which would attract the attention of a prospector searching for coal. They range from one to sixty feet in thickness, and the workable coal beds in any one section vary from five to ten in number. The valuable coal is found in the lower 3000 feet of the formation as at Carbonado, Wilkison, Burnett and Green River.

The Puget formation contains an abundant flora. Fossils are found throughout the Puget formation. These are brackish-water forms. No marine forms have been found in the Puget beds. Willis thinks the beds were laid down in an estuary in which the northern Cascade range formed a peninsula, and the Olympic Mountains an island.[1]

In 1895–6 Willis made collections "from definitely determined stratigraphic horizons on Green River, above Burnett, on South Prairie Creek, and on Carbon River near Carbonado. A preliminary examination of the fossil plants enables Knowlton to report that the lower beds of the series are Eocene, whereas the upper beds may be of Miocene age. . . . . The measured sections of the Puget series exhibit a total thickness of 5800 feet on Green River, 5500 feet on South Prairie Creek, and 5480 feet in Carbon River Canyon. None of these measures is complete. . . . . The sections probably overlap. . . . ."[2]

[1] Cf. CLARK: loc. cit., p. 197.

[2] WILLIS: Bull. Geol. Soc. Amer., Vol. IX, pp. 5, 6, 1898.

On the evidence furnished by fossil plants Sir William Dawson correlates the Puget formation with the Fort Union formation as will be seen from the following quotation:[1]

> In summing up the results of this study of fossil plants from the Tertiary of southern British Columbia, it appears from a comparison with the flora of the Upper Cretaceous Nanaimo series, that the Burrard's Inlet species are distinct and of more modern aspect. On the other hand they are also distinct from those of the older Oligocene or older Miocene deposits of the Similkameen district and other parts of the interior of British Columbia. Between these they occupy an intermediate position; in this respect corresponding with the Laramie of the interior plains east of the Rocky Mountains. They also resemble this formation in the general facies of the flora, which is not dissimilar from that of the Upper Laramie or Fort Union group. We may thus refer the plants [from Burrard's Inlet] now in question to the Paleocene or Eocene, and regard them as corresponding with those of the Atanekerdluk beds in Greenland, the lignitic series of the McKenzie River, and the beds [Kenai?] holding similar plants in Alaska. Thus the opinion expressed in 1890, from the very small collection then available was substantially correct; and I find that the late Dr. Newberry had arrived at a similar conclusion from the study of the plants of the Puget group in Washington territory. This flora thus serves to fill up one of the gaps in our western series of fossil plants, namely, that between the Cretaceous and the Lower Miocene. How completely it may fill this gap we do not know at present. . . . .

THE ARAGO FORMATION

The typical outcrop of this formation is at Cape Arago, Oregon. The beds are chiefly sandstones and shales, and dip toward the northeast at an angle of about 30°. Their thickness is 3000 feet. They contain characteristic Eocene fossils.[2] Diller[3] divides the Arago formation at Coos Bay into the Pulaski formation and the Coaledo formation. The Pulaski is the lower. "The Coaledo formation is characterized not only by the presence of coal, but also by the relatively large proportion of beds containing brackish-water fossils. In the other portion [Pulaski] of the Arago formation of the Coos Bay

[1] SIR WILLIAM DAWSON: Proc. Roy. Soc. Can., n. s., Vol. I, pp. 150, 151, 1895.

[2] DALL: Eighteenth Ann. U. S. Geol. Surv., 1895–6, Part II, p. 343.

[3] Nineteenth Ann. Rep. U. S. Geol. Survey, 1897–8, Part III, p. 320.

quadrangle more than mere traces of coal do not occur, and strata containing brackish-water fossils are rare."[1]

THE MARINE FORMATIONS

THE MARTINEZ FORMATION

The name Martinez was first applied by Gabb[2] to a division of Cretaceous rocks of California. The name comes from the town Martinez, near which typical exposures occur. In recent years the formation has been studied critically by Stanton and by Merriam. "Mr. Stanton has shown the Martinez of Gabb to consist of two parts, one characteristic Cretaceous and inseparable from the Chico group, the other being more closely related faunally and stratigraphically to the Tejon-Eocene than to Chico."[3] The latter was called Lower Tejon by Stanton. Merriam observes that at numerous points on the Pacific coast where the Tejon has been found it always contains an easily recognized fauna. From studies of the faunas in the vicinity of Martinez he proposes (following a suggestion of Stanton) to apply the name Martinez to the Lower Tejon of Stanton.

> In the vicinity of Martinez, the Martinez and Tejon groups form an apparently conformable series between two and three thousand feet in thickness and about equally divided between the two. The faunas, though overlapping, are in the main quite distinct. . . . While some intermingling of species exists, it is not greater than we should expect to find in adjoining groups or periods. . . . The two sets of strata, or two faunas, while belonging perhaps to the two series, represent different periods in the geological history of California, periods quite as distinct so far as faunal evidence is concerned, as the Miocene and Pliocene, or the Pliocene and Quaternary.[4]

The Martinez formation is characterized as "comprising, in the typical locality between one and two thousand feet of sandstones, shales and glauconitic sands," forming "the lower part of a presumably conformable series, the upper portion of which is formed by the Tejon. It contains a known fauna of over sixty

[1] DILLER: loc. cit., p. 320.

[2] Cf. MERRIAM: JOUR. GEOL., Vol. V, p. 767, 1897.

[3] MERRIAM: loc. cit., p. 768.

[4] MERRIAM: loc. cit., p. 774.

species of which the greater portion is peculiar to itself."[1] Its fossils are marine.

THE TEJON FORMATION

This formation was named[2] in 1869 by Whitney, from Fort Tejon, Cal. "The deposits are chiefly conglomerates, sandstones, and shales, in which beds of lignite are not infrequently intercalated, and which less often contain bands of calcareous rock." Clark[3] quotes Whitney (?) as stating that "The conglomerates are very coarse, containing many bowlders from three to six inches in diameter of granite and metamorphic rocks. . . . Portions of the sandstones are very fossiliferous. . . . The strata are very much disturbed, both dip and strike being very variable. . . ." The fossils are marine. Beneath the Tejon is the Chico formation. White, Becker and others state that the Tejon of California lies conformably upon the Chico — the two forming one series.[4] Yet writing of the series at New Idria, Cal., White says, "There is near its middle, a recognizable change of aspect of the strata. . . ."[5] Becker says "The Tejon strata of New Idria are mostly heavy-bedded sandstones of a peculiarly light color, which thus distinguishes them from the tawny Chico standstones."[6]

It is stated also that the Miocene overlies the Tejon conformably. But near Martinez Merriam has shown a pronounced change of fauna, as has been already mentioned. Diller[7] has shown that "All of the facts yet known indicate that in Oregon and northern California there is a faunal and stratigraphic break between the Chico and the Tejon." Perhaps the conformity reported from southern California will be found to be local, or only apparent. Certainly the structural and faunal relations already discussed separate the Tejon from the Chico and from the Martinez. The Tejon is a distinct formation. Near Merced falls, near the boundary of Merced and Mariposa counties,

[1] MERRIAM: loc. cit., p. 775.

[2] Cf. CLARK: loc. cit., p. 100.

[3] CLARK: loc. cit., p. 101.

[4] Cf. CLARK: loc. cit., p. 102.

[5] Quoted by Clark, loc. cit., p. 102.

[6] *Ibid.*

[7] Bull. Geol. Soc. Amer., Vol. IV, p. 220

California, Turner and Ransome describe[1] small patches of Tejon sandstones capping the hills. "This rests almost horizontally upon the nearly vertical edges of the Mariposa [Jura-Trias] slates. . . . The sandstones are overlain to the west by the light colored sandstones of the Ione formation. The two series are probably not absolutely conformable, as the Ione transgresses onto the rocks of the Bed-rock series farther west." Tejon fossils are found in this formation. The Tejon is found in Oregon in the valley of the Willamette River at Albany and at other localities. Clark states that "The Tejon strata of Oregon have been found in a few widely separated localities in the central and northern portions of the state. The most southern yet observed is Coos Bay."[2] But he cites no literature on the the subject, and Diller, in his discussion of the "Coos Bay Coal Field,"[3] makes no mention of Tejon strata.

The Astoria beds at the mouth of Snake River are regarded as Oligocene.

THE UMPQUA FORMATION.

The Eocene described in the Folio of the Roseburg quadrangle, Oregon, rests directly upon an eroded surface of the Upper Cretaceous (Myrtle) formation.[4] There are evidences of considerable erosion in the region before the deposit of the Eocene beds. This leads Diller to believe that Chico may have been present and eroded away. Diller describes the Eocene sedimentary beds under the names "Umpqua formation," from the Umpqua River on which the outcrops occur: "Wilbur tufflentils;" and "Tyee sandstone." The most extensive and important of these is the Umpqua. It lies unconformably upon Cretaceous rocks, and "stretches far beyond the Roseburg quadrangle and plays an important rôle in the makeup of the whole country west of the Cascade Range." The

[1] Geol. Atlas of U. S., Sonora Folio, Calif., 1897.

[2] U. S. Geol. Surv., Bull. 83, p. 103.

[3] Nineteenth Ann. Rep. U. S. Geol. Surv. for 1897–8, Part III, Economic Geology, p. 309 et seq.

[4] DILLER: Geol. Atlas U. S., Roseburg Folio, Ore., 1898.

"formation is composed of an extensive series of conglomerates, sandstones and shales, with terraces here and there of calcareous siliceous beds, which, although of small extent, on account of their exceptional character are treated separately as the Wilbur formation."[1] The Umpqua formation has a maximum exposure of about twelve thousand feet The beds thicken toward the northwest. The bowlders of the Umpqua formation become larger toward the east and south, showing that the land from which they were derived lay in this direction. In places the Umpqua contains abundant marine fossils, *Cardita planicosta* and *Turritella uvasaria* being typical Eocene forms. Thin, small beds of coal also occur.

THE TYEE SANDSTONE

The Tyee sandstone occupies a small area in the vicinity of Roseburg, Ore. "It immediately overlies the Umpqua formation, from whose sandstones it differs chiefly in being heavier bedded and containing more conspicuous scales of mica."[2] It reaches a thickness of about 1000 feet. In places it contains characteristic marine Eocene fossils. The position of the Umpqua and Tyee beds in the geological column cannot be given with certainty. They overlie the Myrtle beds which, according to Stanton, belong to "the lower half of the Upper Cretaceous."[3] Upon the Umpqua, in apparent conformity, lies the "Oakland limestone-lentils" of "probably Oligocene, most likely Upper Oligocene" age.[4] From these relations, from their geographical position and from their fossils I place the Umpqua and Tyee provisionally in the column above the Tejon. If this be their true position they form the latest marine Eocene beds known on the Pacific coast.

THE ATURIA FORMATION

The Aturia beds occur at the water's edge at Astoria, Ore. Formerly they were not distinguished from the overlying shales and sandstones. But in 1880 Condon[5] showed that they are

[1] DILLER: loc. cit. [2] *Ibid.* [3] Quoted by Diller, loc. cit.
[4] DILLER: loc. cit. [5] Amer. Naturalist, Vol. XIV, 1880.

distinct and that the presence of *Aturia ziczac* determines these lower beds to be Eocene or Oligocene. The overlying shales and sandstones do not contain this fossil and are regarded as Miocene. In his "Correlation tables of Tertiary formations: data to 1895" Dall places the Aturia beds in Lower Oligocene, Astoria shales in Upper Oligocene, and Astoria sandstones in Miocene.[1]

UNFOSSILIFEROUS FORMATIONS

THE SPHINX CONGLOMERATE FORMATION

Sphinx conglomerate is the name applied by Peale[2] to a group of nonfossiliferous beds covering an area of about two square miles, but having a thickness of 2000 to 3000 feet. The formation occurs in the Madison Mountain range, Montana. The beds consist of "reddish sandstones and coarse conglomerates of limestone pebbles and bowlders cemented with a reddish sand." They are horizontal and stratified. They are described and mapped as Eocene.

THE PIÑON CONGLOMERATE FORMATION

Weed describes[3] briefly, under the name Piñon conglomerate, certain beds which occur in the southern part of the Yellowstone National Park. He says they consist of a series of conglomerate beds with local intercalations of sandstone, the formation resting unconformably upon the upturned Laramie (Cretaceous)." No fossils are mentioned and they are presumably nonfossiliferous. They are described and mapped as Eocene.

THE SAN MIGUEL FORMATION

The San Miguel formation was named by Purington[4] and referred by him to the Eocene "because of the great unconformity at its base and because it underlies the volcanic complex, which is thought to be of Eocene age in the portions here developed." It occurs near Telluride and Silverton, Col., and rests

[1] Eighteenth Ann. Rep. U. S. Geol. Surv., 1895–6, Part II, pp. 327–348.

[2] Geol. Atlas of U. S., Three Forks Folio, Mont., 1896.

[3] Geol. Atlas of U. S., Yellowstone National Park Folio, 1896.

[4] Geol. Atlas of U. S., Telluride Folio, Col., 1899.

unconformably upon Mesozoic and Paleozoic strata. No fossils have been reported from it. It consists of a coarse, variable conglomerate. Its thickness varies from a few feet to 1000 feet. It is thicker toward the west and dips toward the east.

Some geologists, however, would dispute the right of the San Miguel formation to a place among the Eocene formations on the grounds on which Purington places it there. If it is admitted to the Eocene epoch, there would seem to be no good reason for excluding a number of other formations, among which are the Denver and the Arapahoe beds. Geologists appear to be not fully agreed upon the criteria that shall determine the base of the Eocene.

INTERPRETATION

Having reviewed the various Eocene formations of the region, we may now consider some of the conditions presented by the region as a whole, and some of the problems involved in its history.

Physiography and Climate.— On the Pacific coast the Tejon as now known was deposited in marine water which occupied the great valley of California and western Oregon. It is not known whether the beds of Oregon and California were connected with each other or not. This interior sea in which the Tejon of California was deposited probably connected with the ocean in southern California. There may have been several connecting channels. No definite knowledge exists upon the subject. Before the end of the Tejon deposition the Chico area in Oregon, which had been land and subject to erosion, went down beneath the sea, and beds of Upper Tejon age, possibly underlain by Martinez, were deposited upon it. Probably the same subsidence admitted the sea in which the Umpqua and Tyee beds were deposited a little farther to the southwest. If so, these beds are to be correlated with the Tejon. The correlation of these geographically separated beds must finally be decided by their fossils.

The plants of the Kenai formation indicate a temperate climate at the time of their growth. This climate probably

prevailed over North America, Greenland and Europe, reaching to Spitzbergen. Dall says[1] it may be considered as reasonably certain "that the period during which in the arctic regions the last temperate flora flourished was in a general way the same for all parts of the arctic. It would seem highly improbable that a temperate climate should exist in Spitzbergen and not at the same time in Greenland and Alaska, or *vice versa.*" Moreover the nature of the plants of the regions named forms the basis of this statement. The Kenai beds are regarded as fresh water deposits and represent a low land area, which was subsequently still further depressed allowing the Miocene sea to cover it. Dawson[2] says:

> It would be rash to decide on the climatal conditions on the west coast of America in the Eocene period, from the plants yet known. But so far as they can give information we may infer that the Cretaceous climate was somewhat warmer than that of the Eocene, but that both attained a higher temperature than that of the present day in the same latitudes, while in the Miocene age the climatal conditions were not very different from those now prevailing in the region.

The Fort Union beds are perhaps the oldest that have been certainly determined to be Eocene. They occupy the plains region of the north. Their limit to the south is unknown, but Haworth[3] believes that near the beginning of Eocene time Tertiary deposits spread continuously from the Dakota-Nebraska area over western Kansas, Indian Territory, and Texas.

Immediately succeeding or perhaps in part contemporaneous with the Fort Union deposits a series of so-called lake deposits was formed on the plains of the summit region bordering the Rocky Mountains on the east. Elevation or warping of the continent and especially of the mountains of this region appears to have checked the drainage in certain directions, so as to form lakes. The oldest and lowest of these deposits are toward the south and west (Puerco); the newest and highest toward the north and east. Probably during Eocene time the uplift in this

[1] Seventeenth Ann. Rep. U. S. Geol. Surv. 1895–6, Part I, p. 839.

[2] Proc. Roy. Soc. Can., n. s., Vol. I, p. 151, 1895.

[3] The Univ. Geol. Surv. of Kans., Vol. II, p. 253, 1896.

region was greater in the southwestern part than in the northeastern part.

THE ORIGIN OF THE SO-CALLED LAKE DEPOSITS

The stratified deposits of the Wasatch, Bridger, Uinta, and others of like nature have been regarded and referred to as lake deposits. Dutton seems to have been the first to recognize and to point out the fact that some of them are not of lacustrine origin. As early as 1880, in his report on the High Plateaus of Utah he says:[1]

> There is another class of conglomerates which claims our special attention. These are of alluvial origin, formed, not beneath the surface of the sea nor of lakes, but on the land itself. They do not seem to have received from investigators all the attention and study which they merit. . . . . Throughout great portions of the Rocky Mountain region they are accumulating today upon a grand scale and have accumulated very extensively in the past.

He then describes the formation and coalescence of alluvial cones containing well-stratified material. Yet this idea of subaërial deposition seems not to have been further emphasized either by Dutton or by others. For a little later he writes[2] "The whole region [High Plateau], with the exception of the mountain platforms and preëxisting mainlands, has passed through this lucastrine stage."

In 1896 Gilbert[3] clearly interpreted certain stratified deposits of Colorado as fluviatile. He speaks thus of the Upland sands and gravels of the Arkansas River basin:

> Whatever the cause the streams which flowed from the mountains onto the plains, and thence eastward across the plains, ceased to carve valleys in the region of the plains, and began to deposit sediment. When they had filled their channels so that their beds lay higher than the neighboring country, they broke through their banks, shifting their courses to new positions and they then came to flow in succession over all parts of the plains, and to distribute their deposits widely, so that the whole plain of the district here described was covered by sands and gravels brought from the canyons and valleys of the Rocky Mountains.

[1] Geol. of the High Plateaus of Utah, pp. 219 et seq., 1880.

[2] The Grand Canyon of the Colorado, p. 216, 1882.

[3] Seventeenth Ann. Rep. U. S. Geol. Surv. for 1895–6, Part II, pp. 575, 576.

In studying the Tertiary deposits of Kansas Haworth reaches similar conclusions. He says:[1]

> The relative positions of gravel, sand and clay of the Tertiary over the whole of Kansas . . . . correspond much better to river deposits than to lake deposits. . . . It is quite possible that during Tertiary time . . . . lesser local lakes and lagoons and swamps and marshes may have existed in different places and for varying lengths of time. But when we consider the Kansas Tertiary as a whole and yet in detail, it must be admitted that the materials themselves have many indications of river deposits and a very few of lake deposits.

Matthew,[2] in discussing the question whether the White River Tertiary is an eolian formation, considers the objections to the lacustrine hypothesis and gives reasons for his believing it to be of eolian origin. He reaches the conclusion that the "White River clays in Colorado, at least, are chiefly eolian deposits. . . . . Most of the sandstones are probably fluviatile. . . . . Some sandstones may be eolian" (407). This position, however, cannot at present be regarded as established; but the question of lacustrine origin is shown to be an open one.

In 1897 Davis,[3] in discussing the origin of the Denver formation, gives criteria for distinguishing lacustrine from fluviatile deposits. In a later publication[4] the same author compares lacustrine with fluviatile deposits as follows: "In both cases the deposits are stratified; in both cases the deposits may include fine as well as coarse materials; in both cases the area of distribution may be large as well as small; in both cases the thickness of deposits may be great as well as light; in both cases the strata may bear ripple-marks, mud-cracks, cross-bedding, and other indications of small and variable water-depth. With all these similarities, it would not be remarkable if a lake deposit were sometimes called a river deposit, or if a river deposit were

[1] The Univ. Geol. Surv. of Kans., Vol. II, p. 283, 1897.

[2] Amer. Naturalist, Vol. XXXIII, pp. 403–408, 1899.

[3] Science, U. S., Vol. VI, pp. 619–621, 1897.

[4] Freshwater Tertiary Formations of the Rocky Mountain Region. Proc. Amer. Acad. Arts and Sci., Vol. XXXV, pp. 345–373, 1900.

mistaken for a lake deposit; for the safe discrimination of the two classes of deposits must depend on their differences, not on their resemblances. While the marginal sediments of a lake may be coarse, the body of the central sediments must be fine and uniform. The marginal parts of a fluviatile deposit may also be coarser than the forward parts, but the latter may be characterized by frequent variations of texture and structure, and occasionally by filled channels and lateral unconformities" (p. 371).

Some quotations may be given to show that many descriptions of the so-called lake beds would apply equally well to river deposits. Lake terraces are "well marked between Ralston and South Boulder creeks (Colorado), where there is a *blending of lake and river terraces*.[1] Here five distinct terraces are traceable, the lake terraces extending from 100 yards to three miles eastward from the foothills, while those more distinctly of stream origin are from 200 to 700 feet in width."[2] Here the lake and river terraces are not clearly distinguished: the width of the terrace seems to be the principal criterion, and the limits assigned to lake and to river terraces overlap. According to the figures given, the river terraces here reach a width of 700 feet, while some of the lake terraces are only 300 feet wide. Again, from the same monograph, with reference to the present inclination of both Tertiary and Pleistocene deposits, it is said that there is an inclination "in round numbers of ten feet to the mile from the foothill region to the valleys of the Missouri and Mississippi;" this would not admit of the holding of lake waters."[3]

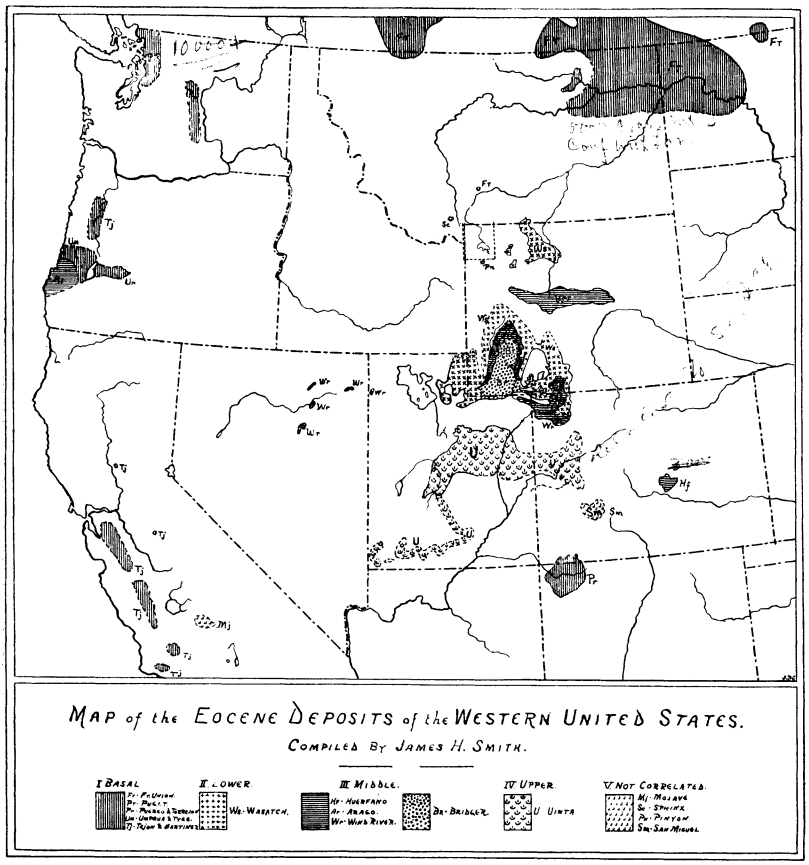
King's Report of the Survey of the 40th Parallel abounds in descriptions of so-called lake beds like the following: "Rough, gritty conglomerates, passing up into finer-grained sandstones, and at certain points developing creamy, calcareous beds" (p. 405). The most characteristic exhibition is in the basin of Vermillion Creek, where a fuller section is displayed. It is made up

[1] The italics are mine.

[2] EMMONS: Geol. of Denver Basin, Monograph XXVII. U. S. Geol. Surv., p. 9, 1896.

[3] *Ibid.*, p. 40.

of a heavy, gritty series at the base. . . . . The middle members are of finer material and are more intercalated with clays, ... while the upper part of the series . . . . is made up of striped and banded sandstones varying from gray to yellow, white and red, with prevailing red and white tints" (p. 375).



Enough has been said, perhaps, to show that no single explanation will account for the deposition of all the so-called lake beds. At present it seems probable that the deposits will be found to be in part lacustrine, in part fluviatile, and possibly in part eolian. The origin of these deposits cannot be solved by

theoretical considerations alone. Only extensive, critical study in the field will furnish the data upon which the final conclusions must be based. It will be well if the investigator shall enter the field with a clear knowledge of the facts already known, with the possibilities of the different modes of deposition and with the criteria for distinguishing these modes well in mind; and with a willingness to be led to any conclusion to which the facts may conduct him.

CORRELATION TABLE[1]

Eocene	Pacific Coast	Interior	European
Upper	Foraminiferal Shales (?)	Uinta Bridger (upper part)	Ligurien
Middle	Arago	Bridger: Bridger-Huerfano (upper) Wind River-Huerfano (lower)	Bartonien Lutetien
Lower	Kenai (?)	Wasatch	Suessonien
Basal	Tyee Umpqua (?) Tejon Martinez Puget	Torrejon Puerco Fort Union	Thanetien Montien

JAMES HERVEY SMITH.

[1] Cf. DALL: Eighteenth Ann. Rep. U. S. Geol. Surv., Part II, table facing p. 334, 1897. SCOTT: Science, n. s., Vol. II, p. 499, 1895. Also Introduction to Geology, p. 496. OSBORN: Science, n. s., Vol. XI, p. 562, 1900.

Many Eocene formations, not yet correlated, are omitted from the table.